National Aeronautics and Space Administration

Multi-Functional Flash Lidar for Precision Safe Landing in Challenging Terrains

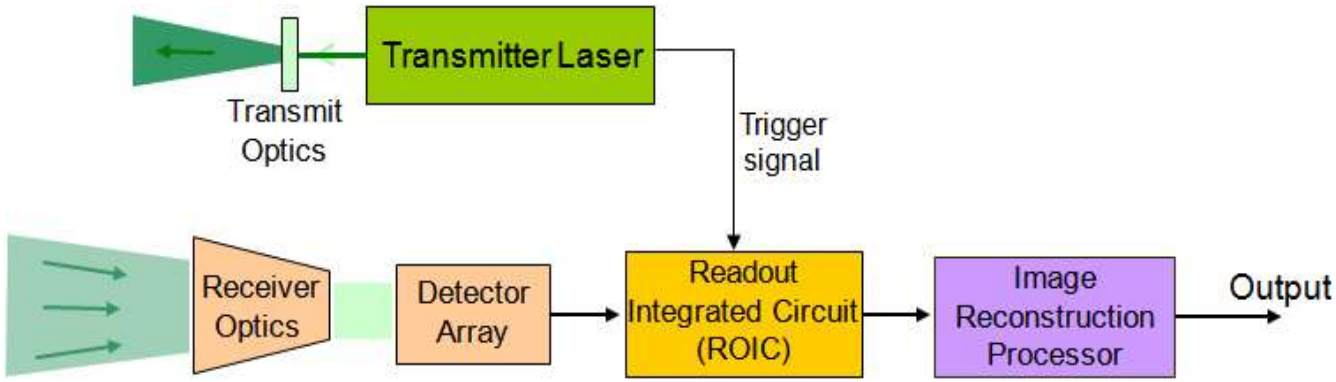
Farzin Amzajerdian, Paul F. Brewster , Alexander Bulyshev, Aram Gragossian , Jacob M. Heppler , Frederick G. Wilson , Glenn D. Hines , Sean A. Laughter , and Daniel K. Litton

NASA Langley Research Center

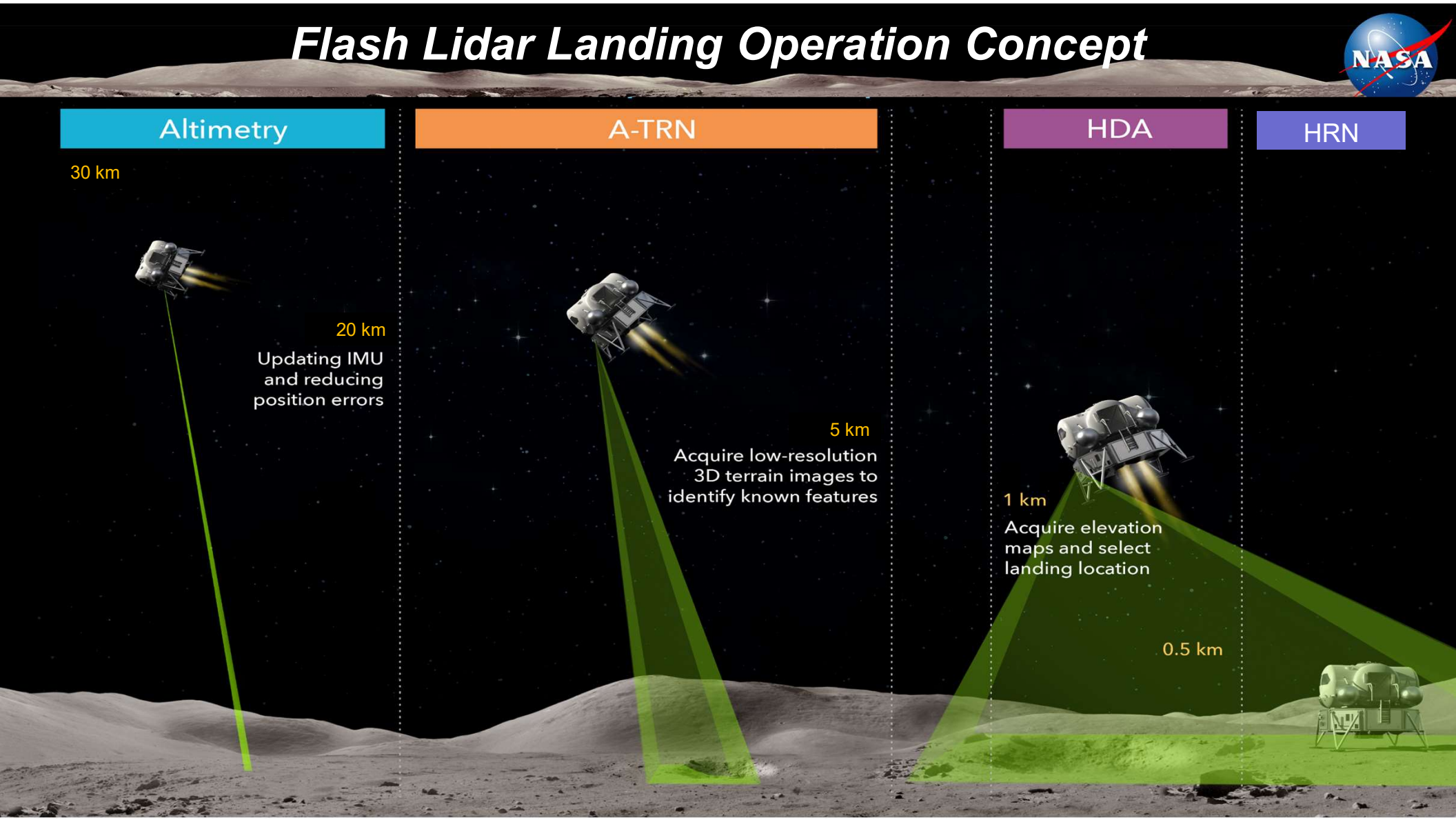
AIAA SciTech Forum 2024

3-D Imaging Flash Lidar Sensor

- **Flash lidar presents several advantages over scanning lidars for hazard detection and safe landing on planetary bodies**
  - Does not require vehicle motion correction
  - Generates organized 3-D pattern (does not need oversampling of the landing site)
  - Able to perform other functions critical for precision navigation



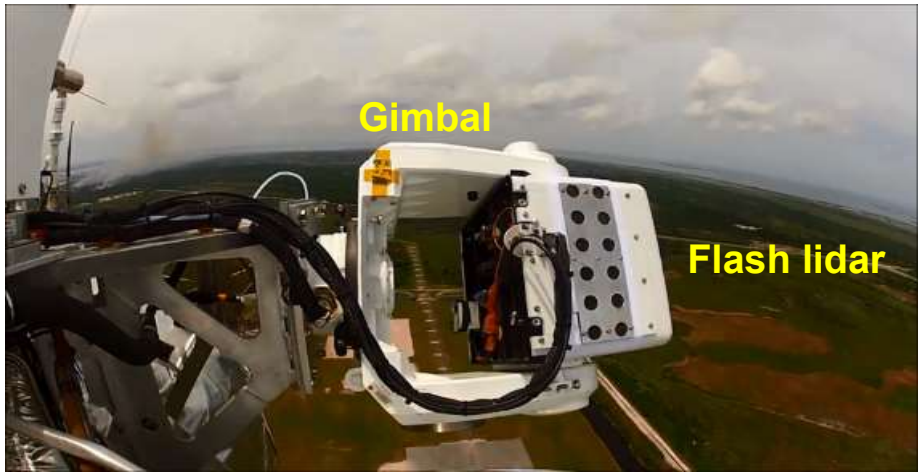
Flash Lidar Landing Operation Concept



Flash Lidar Descent and Landing Requirements

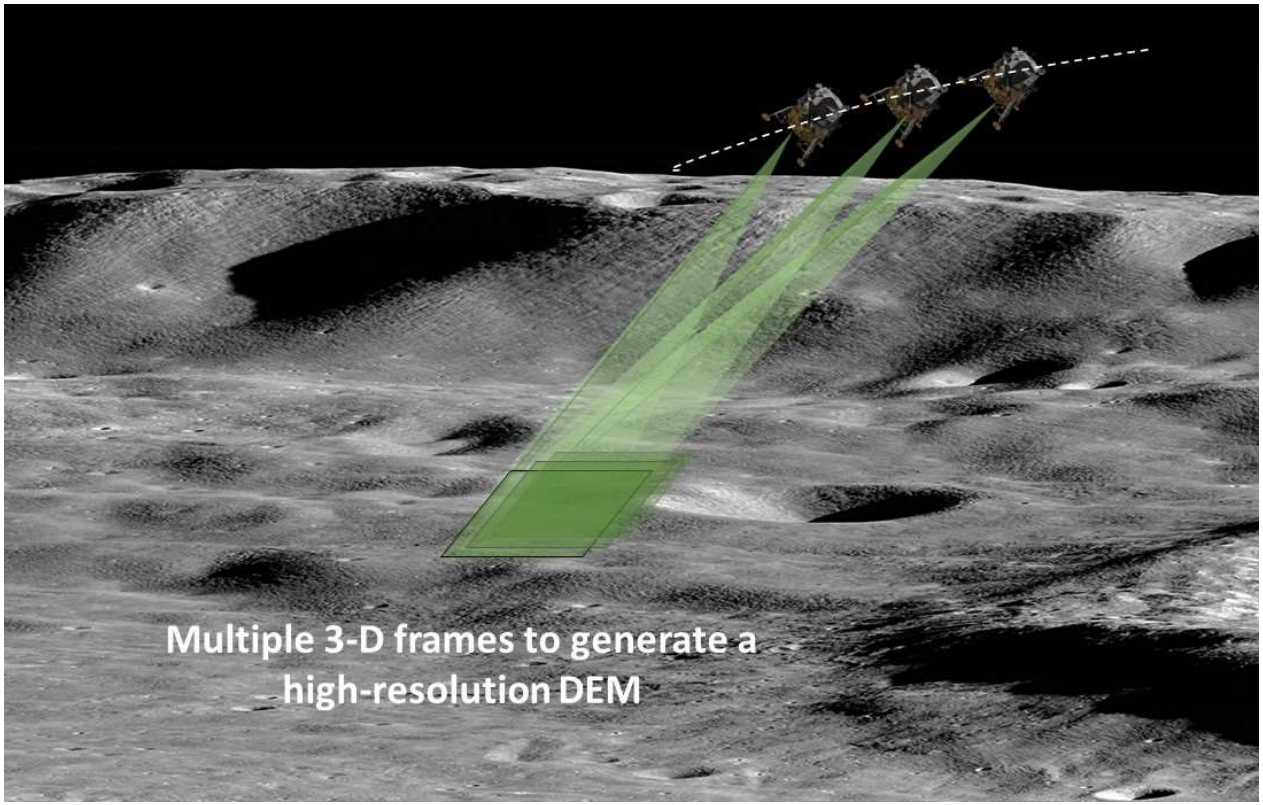
- Commercial linear-mode flash lidar camera has 128 x 128 = 16.4k pixels
- Mapping 100 m x 100 m area with 14 cm Ground Sample Distance (GSD) or 70 m x 70 m area with 10 cm requires 0.5 M pixels
- Developed a Super-Resolution algorithm to meet HDA requirements without the need for a mechanical gimbal or scanning mirror

Flash lidar closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)



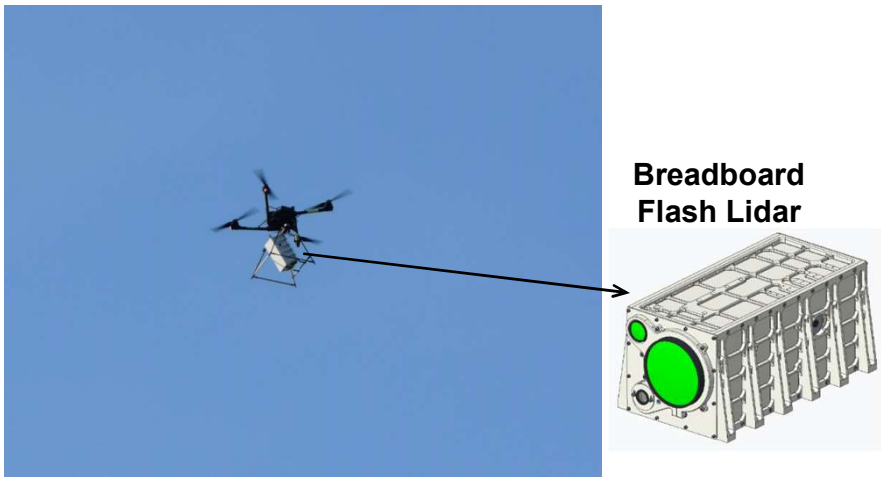
Flash Lidar Super-Resolution Algorithm

- **Super-Resolution (SR) technique uses a set of consecutive frames, from slightly different positions and angles (resulting from platform motion), to generate a high-resolution DEM**
- **No external sensor data is required**
- **Generates high-res DEMs at 1 Hz rate using 20 frames**

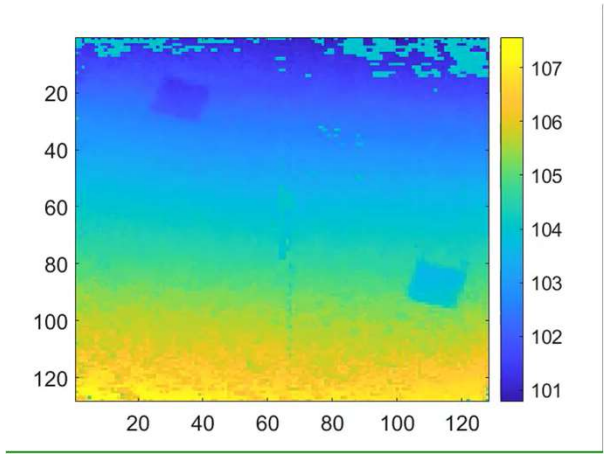


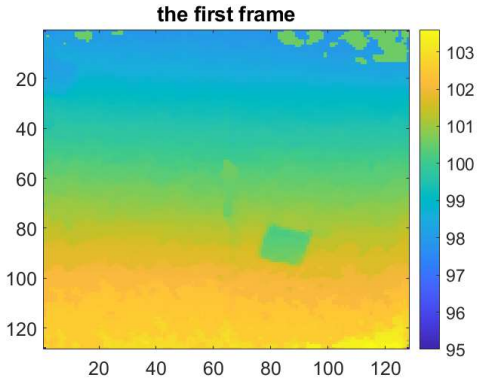
Drone Flight Tests
Using Breadboard Lidar with Real-Time SR algorithm

- **Conducted 3 drone flight tests at LaRC in 2023**
- **Flights were limited to 120 m altitude**
- **Objectives:**
  - Assess and fine tune calibration and SR algorithms
  - Characterize range image quality

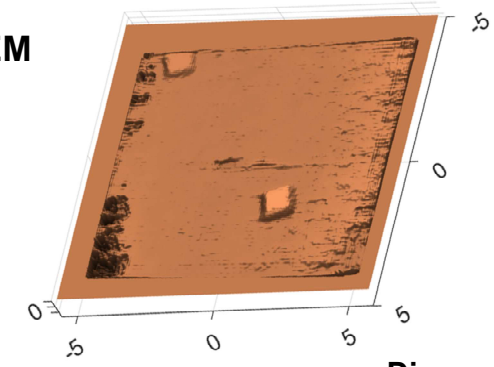


Drone Flight Tests at LaRC





SR DEM

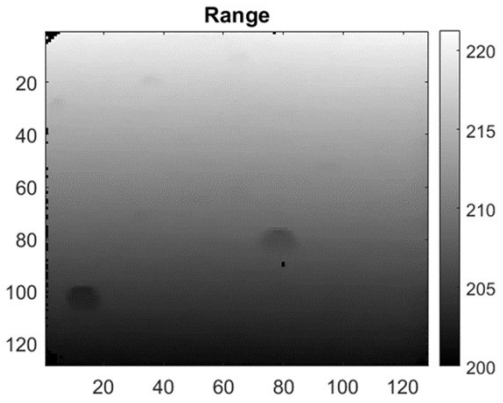


Dimensions in meters

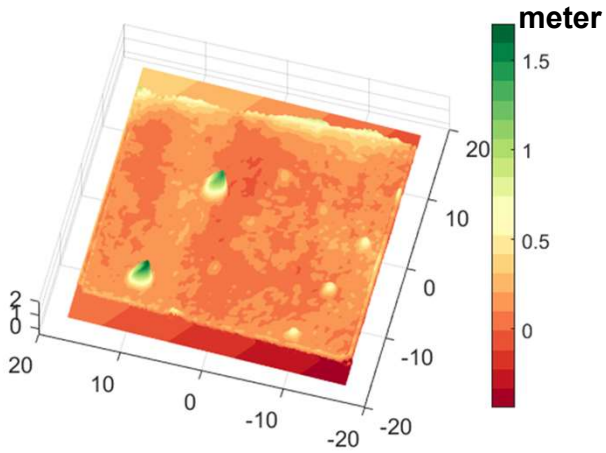
Helicopter Flight Test Results

- **SR algorithm generated high quality DEMs from 340 m distance @ 45º look angle**
- **100% hazard detection at ranges < 250 m**
  - Smallest hazard: 25 cm dia x 35 cm height

Single Frame

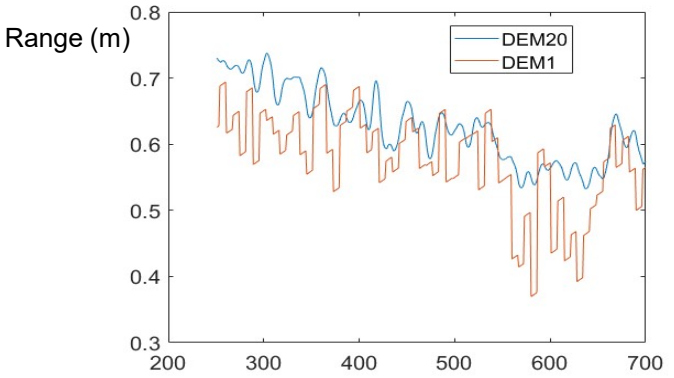


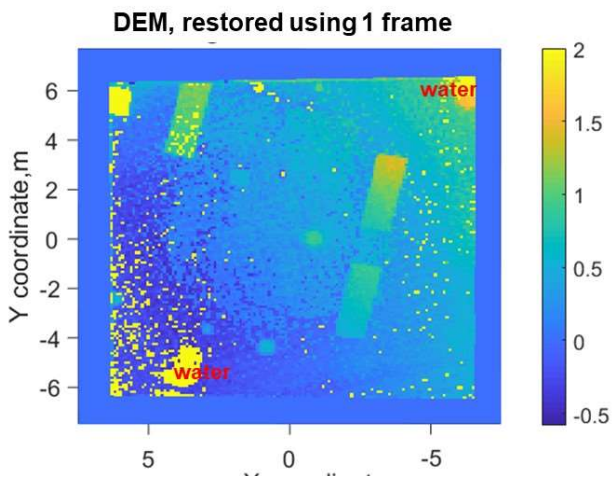
Real-time Elevation Map

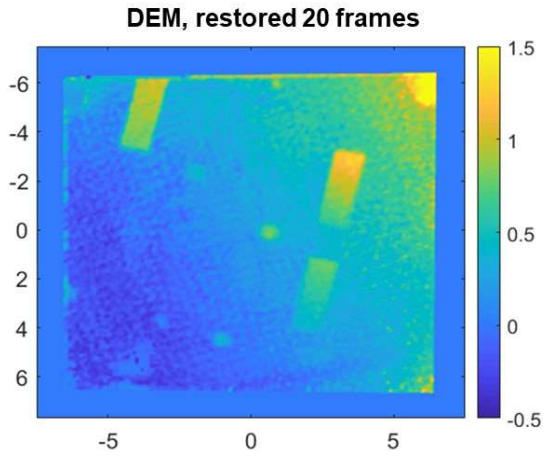


Performance of Real-Time Super-Resolution Algorithm

- Generated DEMs at 1 Hz rate with ~ 30 msec latency
- Resolution enhancement by 25X (0.4M pixels)
- Range resolution enhancement by 2X (4 cm)
- Range noise reduction by > 2X (3 cm)
- Effectively recovered dark pixels

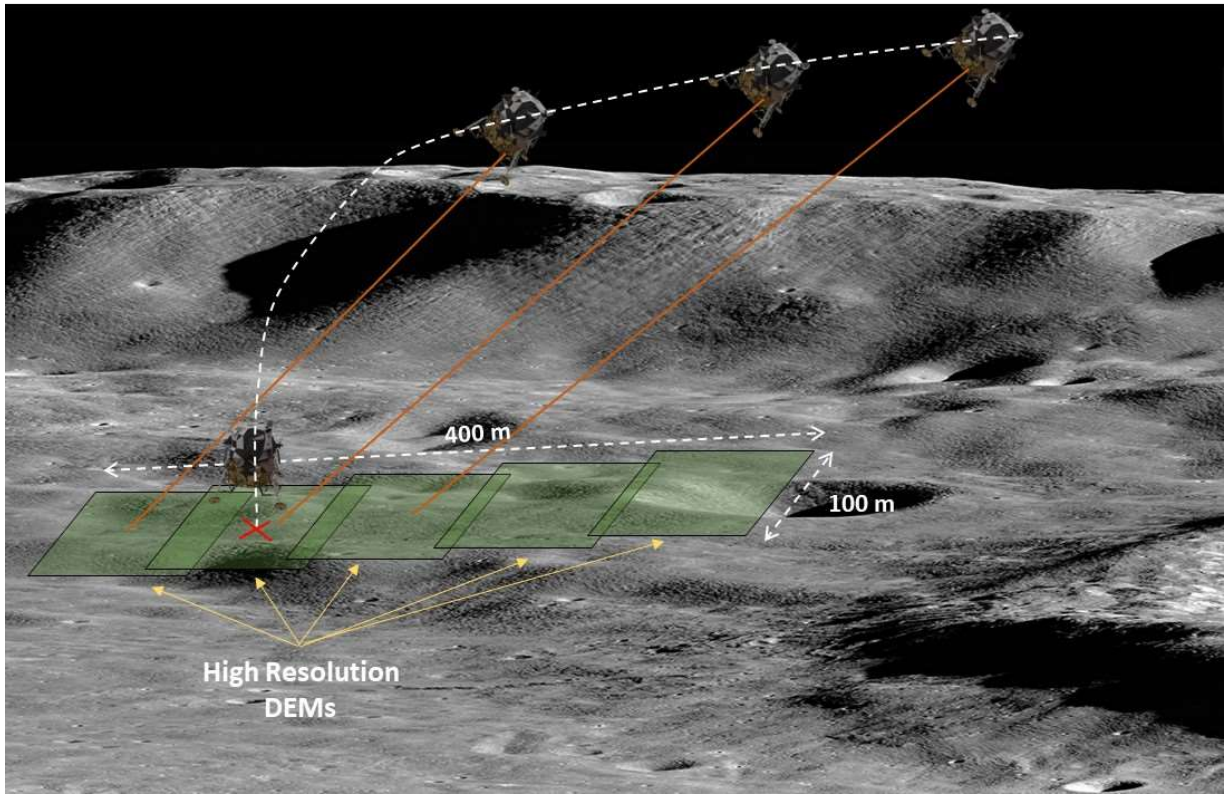




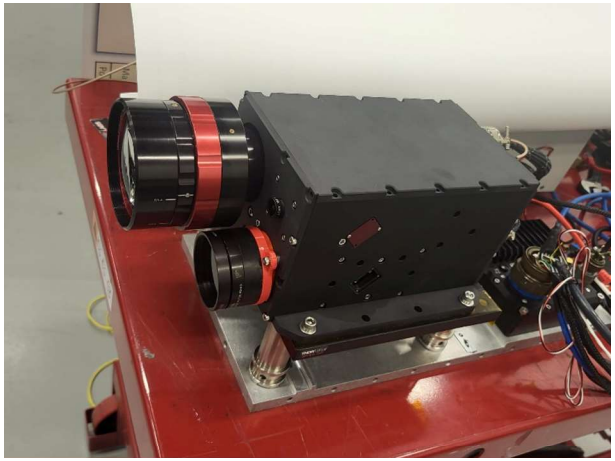


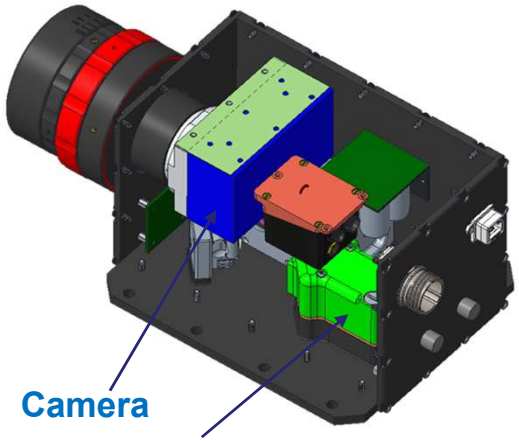
Flash Lidar Generates Multiple High-Resolution DEMs

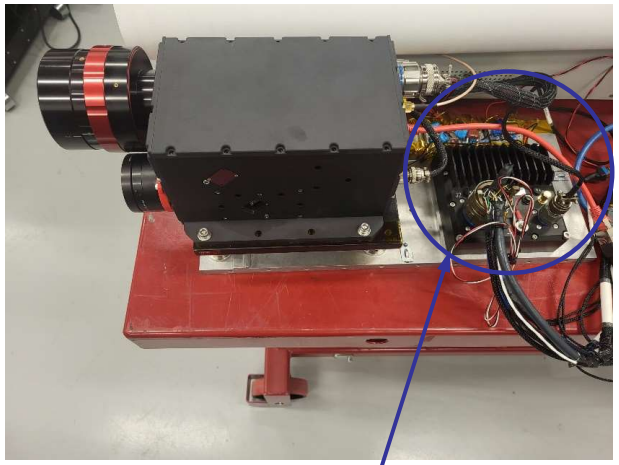
- DEMs and Hazard Maps are generated every 1 second with 30 msec latency
- Can cover up to 100 m x 400 m area and identify safe landing locations in 5 seconds



Multi-Functional Flash Lidar







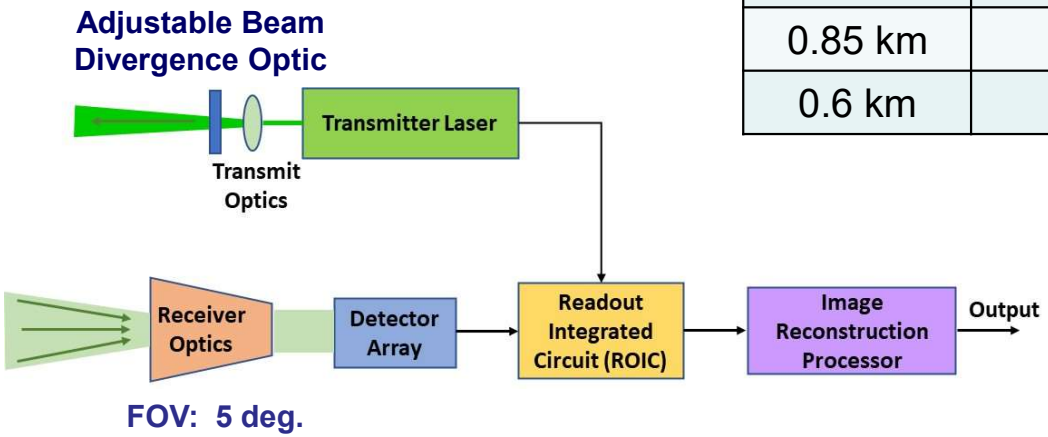
Dimensions	Sensor Head	11.8”x6.6”x4.7”
	Controller box	9.0”x9.0”x2.5”
Weight	Sensor Head	8.5 lb
	Controller box	5.5 lb
Power		55 W

Transmitter Beam
Divergence Wheel

Flash Lidar Multifunctional Operation

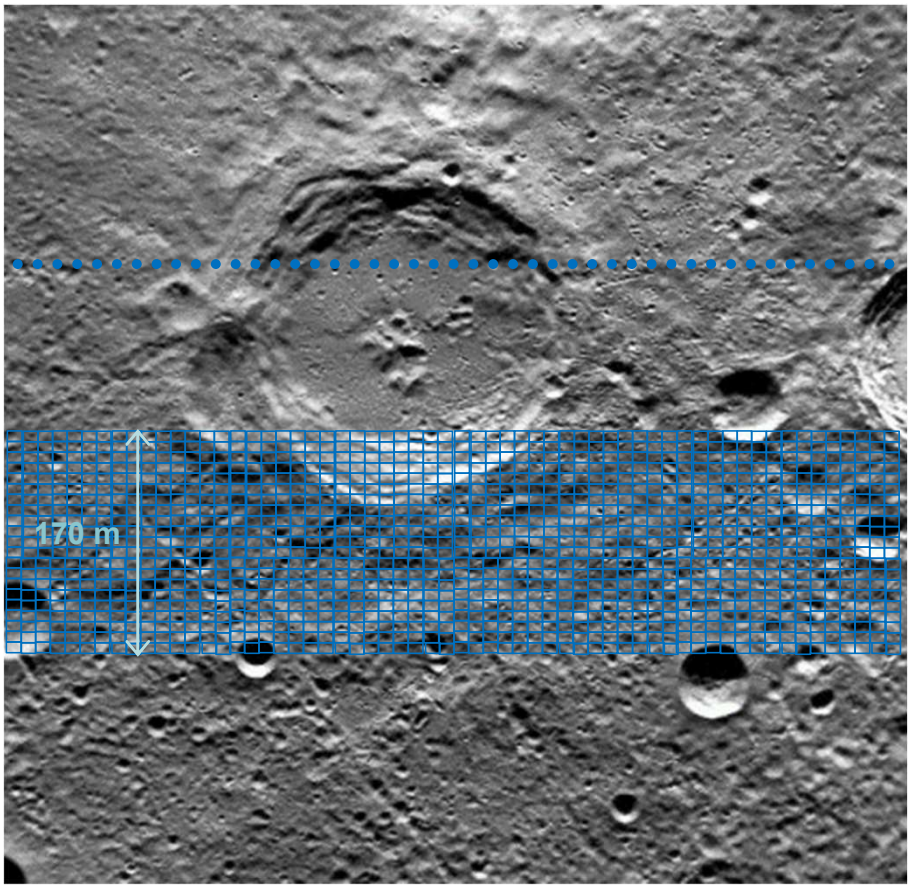
- **Laser beam divergence is reduced to extend operational range for altimetry and active TRN functions**

Altitude	Function	Beam Divergence (deg.)	GSD (m)	No of Illuminated Pixels
30 km	Altimetry	0.25	20.5	5 X 5
20 km	TRN	0.5	13.7	8 X 8
10 km	TRN	1.0	6.8	16 X 16
0.85 km	HDA	5.0	0.78	128 X 128
0.6 km	HDA	5.0	0.58	128 X 128



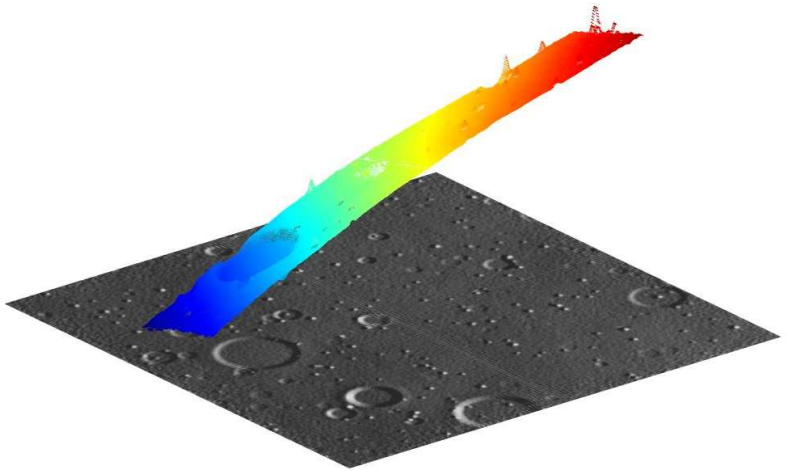
Flash Lidar TRN Function

- **Active TRN options**
  - **Laser Altimeter: Generates a contour of terrain**
    - Limited precision
    - Probability of gross position error
  - **Flash Lidar: Generates a swath**
    - Allows for better matching with reference map
    - 5.0^{o} receiver FOV generates 109 m wide swath (16 pixels X 6.8 m) from 10 km altitude



Flash Lidar TRN Function

- **SR algorithm can be utilized to reduce the effective image pixel size for TRN**
  - Significant overlap of image frame at 20 Hz
  - Reduces image pixels to less than 4 m
  - LOLA elevation maps have 5 m pixel size

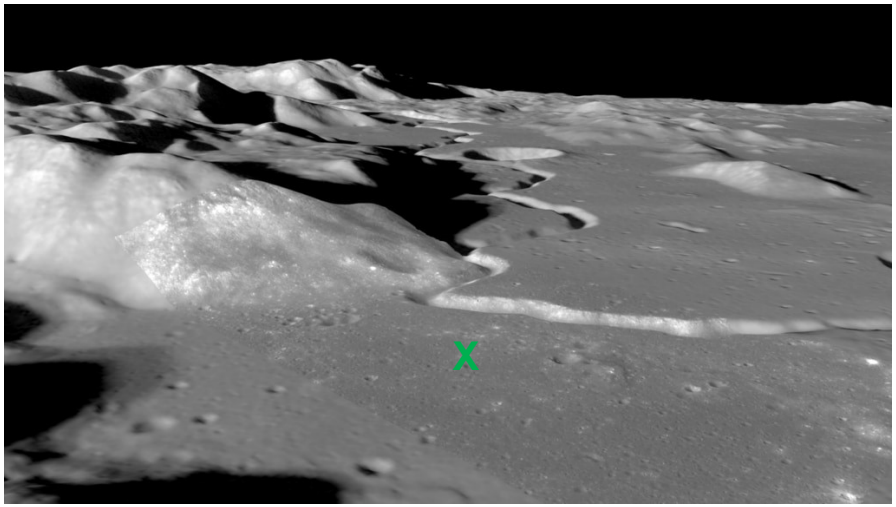


Backup

Landing missions are progressively more ambitious

- Past landing missions generally selected benign terrains
- Objectives of future landing missions:
  - Sustainable human presence at the Moon and continued human exploration on towards Mars
  - Exploration of Jupiter and Saturn Moons (e.g., Titan, Europa), and Asteroids

Apollo 15 Landing Site



Artemis Landing Site

Closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)

Flash Lidar Generates Multiple High-Resolution DEMs

- Multiple DEMs with ~50% overlap allows for application of Differential technique to eliminate the possibility any false negatives (missing hazards)
- Generate a single 100 m x 200 m Hazard Map in 5 seconds with 40 msec latency